Water Injection and Dust Removal in High-Pressure and Low-Porosity Coal Seam

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Abstract: Dust pollution is very serious in coal mining process, which is a great threat to the underground staff health and equipment and facilities safety. Coal seam water injection in mining process is an effective way to reduce coal mine dust concentration at the source. However, the effectiveness of water injection is limited in high-pressure and low-porosity coal seam. To improve the moisture content of coal seam, expand the wetting range and enhance the effect of dust reduction by water injection, the injectability and influencing factors of coal water injection are analyzed by numerical simulation method, and the sealing technology under high-pressure condition is studied. Then, according to the practical conditions of Tangkou coal mine, the parameters and process system of process system are designed, the effect of high-pressure water injection in coal seam was determined by testing water injection quantity, water increment and dust concentration. It is showed that the dust-removal rate of the high dust concentration operation such as falling coal and moving frame is 63.49% and 59.72%, the maximum dust-removal rate of multi-processes is 53%, which achieve a high level of application. The research results in this paper is of important theoretical and practical value to improve the water injection effect of high-pressure and low-porosity coal seam and improve the efficiency of dust removal in coal mining process.

Keywords: high-pressure and low-porosity, coal seam water injection, dust removal technology, field test

1. Introduction

With the increasing of the depth and mechanization of coal mining, coal dust, the impact of ground pressure, ground temperature and other natural disasters continue to upgrade the harm degree (Wang 2011, Wu et al 2012), disaster incidents occur frequently, which seriously threaten the safe and efficient mining and the physical and mental health of underground staff. Coal seam water injection can effectively reduce the coal dust when coal crushing, prevent the impact of mine pressure, coal and gas outburst disasters, by increasing the thermal conductivity of coal, reduce coal temperature, and prevent spontaneous combustion of coal. In addition, coal seam water can soften the hard coal, so that speed up the recovery rate, improve coal production and efficiency (Wu et al 2008, Nie et al 2007). However, the coal seam in many mining area is with high-pressure and low-porosity feature, Coal joint cracks are not developed and relatively hard, water injection is difficult in these coal seams, then the desired disaster prevention effect cannot be achieved (Jin et al 2001, Zhao et al 2000). In this paper, the numerical simulation and field test methods are used to design the high-pressure and low-porosity coal seam water injection technology, so as to solve the difficult problem of coal dust control in high-pressure and low-porosity in deep well mining process.

2. Numerical Simulation of Moisture Permeability Range and Wetting Radius

2.1 The establishment of the model

The model is solved by finite element method. The radial range of the borehole is calculated as a two-dimensional model and the roof and the floor are set as the barrier boundary. According to the principle of wet superposition and geometric symmetry, a 1/4 part of the radial range of the borehole is taken as the calculation area (Jin and Ou 2005, Chen et al 2011). Figure 1 shows the regional calculation of single well water injection.

Figure 1. The diagram of single hole water injection calculation area.

The thickness M of the coal seam is 9.0 m, H_i is mining height; the buried depth is 550 m and the effective porosity

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is 0.049, and the gravity is 1.32 t/m^3 . Water injection pressure $P=7.0 \text{ MPa}$; simulated water injection time is 90h and the initial time step is 0.05h. The permeability direction of the coal seam and the lateral anisotropy ratio $k=0.34$, the no-load permeability coefficient $K_p=4.1 \times 10^{-8} \text{ m}^2 \text{Pa}^{-1} \text{h}^{-1}$, the water infiltration coefficient range $K_{xx} = 10^{-10} \sim 3.2 \times 10^{-8} \text{ m}^2 \text{Pa}^{-1} \text{h}^{-1}$; water storage coefficient range $S=2.3 \times 10^{-8} \sim 0.1 \times 10^{-6} \text{ Pa}^{-1}$ (Nie et al 2011, Ma et al 2009, Li et al 2006). Figure 2 is the grid division.

Figure 2. The diagram of some grids.

2.2 Simulation results analysis

(1) Dynamic Process of Water Inflow Distribution under 7.0MPa Water Injection Pressure

Figure 3. The dynamic process of water inflow distribution under 7.0MPa water injection pressure.

It can be seen from Figure 3 that under the water injection pressure of 7.0 MPa, with the increasing of water injection time, the wet distribution of coal is increasing. For example, when the time of water injection is 3.71 h, the wet range is less than 2.0m; when the time of water injection is 45 h, the wet range is more than 4.0 m and when the time is 90 h, the wet radius $R_{(0.5)}$ is more than 6.0 m. It can be seen that the main features of the coal seam water injection in the fully mechanized top coal caving face are that the thickness of the coal seam is large; the general direction is large; the

water injection flow is large; the water injection time is long and the water movement is comparatively slow along the level. When the water is injected under the same pressure, the flow is high and the water moves faster around the borehole. As the wetting range expands, the water movement speed is slowed down and the flow rate decreases, and the water injection efficiency goes down. When the water approaches the top plate, it moves in parallel along the plane direction at a relatively stable speed. And the speed decreases slightly thereafter. With the appropriate increase in water injection pressure, water injection speed. Here are two explanations. First, the power of water delivery has been improved; Second, the structure of coal is destroyed and the penetration capacity is significantly improved. According to the principle of superposition, taking the water value 1% as a wet boundary of coal, the wetting boundary of single hole water injection is 0.5%.

(2) Simulation results of wetting distribution after 90.00 h under different water injection pressures

Figure 4. Simulation results of wetting distribution after 90.00 h under different water injection pressures.

It can be seen from Figure 4, during the same water injection time, with the increasing of water injection pressure, the wet distribution of coal has gradually increased. Compared with 7.0 MPa water injection pressure, when the water injection pressure is 10.0 MPa, the position of 0.5% of the wet hole of single hole water injection has increased from 6.0m to close to 8.0m. Because the water injection drilling distance is 2 times of the wet radius, taking into account the dynamic and static pressure of injection is between 5.0~18.0 MPa, and usually it is more than 10.0 MPa, a reasonable water injection drilling distance is 16.0 m.

(3) Moisture ranges and injection time under different water injection pressures

Figure 5 shows that the wetting range is increasing with the water injection time under the same water injection pressure. The higher the water injection pressure, the faster the wetting range increases with the increase of the water injection time. In the same water injection time, the wetting range increases with the increase of water injection pressure. Low pressure water injection method requires a longer water injection time to achieve the same wet range of coal. Fixing a water injection pressure, it can be very easy to find the required water injection time when the wetting radius $R_{(0.5)}$ of the coal on both sides of the borehole is a certain value. For example, when the water injection pressure is 13.0 MPa and the wet radius $R_{(0.5)}$ is 6.0m, the required time is about 40.0 h.

Figure 5. Wetting ranges and injection time under different water injection pressures.

3. Brief Introduction of 5304 Working Face in Tangkou Mine

5304 working face of Tangkou coal mine is a fully-mechanized top coal caving working face, the strike length and trend length of the working face are 1565 m and 230 m. 5304 working face mined along the goaf, which is with a strong risk of shock. The vertical stress in this region is high, porosity is close to 4%, The water injection porosity in some locations is only 2.1%, so the coal seam of 5304 working face is a high-pressure and low-porosity coal seam, which is hard to inject water.

4. Industrial Test of High-Pressure and Low-Porosity Coal Seam Water Injection

4.1 Coal seam water injection technology

According to the specific geology and the law of rock pressure of 5403 working face, the current seam water injection technology adopts the water injection mode of combining dynamic and static pressure, meaning that in the dynamic pressure area adopts static pressure injection method and in the static pressure area adopts the dynamic pressure water injection method. Therefore the working face 5304 water injection site will use dynamic pressure water

injection system and static pressure water injection system successively. Two different arrangement forms of water injection system are shown in Figure 6 and Figure 7.

Figure 6. The diagram of static pressure water injection system.

In Figure 6, 1-water pipe, 2-pressure gauge, 3-water meter, 4-valve, 5-shunts, 6-high pressure hose, 7-sealing segment.

Figure 7. The diagram of dynamic pressure water injection system.

In Figure 7, 1-water injection borehole, 2-water injection pipe, 3-sealing segment, 4-shock resistance pressure gauge and flow meter, 5-check valve, 6- shunts, 7-high pressure pipe, 8-control valve, 9-flow meter, 10-high pressure water injection pump, 11-water container.

The coal seam water injection technology adopts the water injection mode of combining dynamic and static pressure. The coal seam starts drilling in the distance from advance support about 20 m and boreholes are numbered from inside to outside in turn. The test area length is about 165 m. Because advance support is about 60 m, the drilling construction location is at a distance from advance support about 20 m. That is to say the first injection hole is at a distance from the working face about 80 m and the distance covers the most dynamic pressure area basically, but the advanced support conditions limit the drilling construction of water injection in the region. Therefore, in the initial period of the coal seam water injection, dynamic pressure water injection is all adopted, meaning that high pressure water-injection pump is used to inject high pressure for coal body. The boreholes adopt mode that borehole-drilled with water injection at the same time until the working face advance support reaches water injection location. That is to say when the hole location enters to dynamic pressure area, the pattern for the water injection is changed to static pressure water injection and other boreholes follow the same pattern until boreholes are ahead of working face 10 m. Boreholes achieve the effect of wetting coal body relying on the capillary force of coal body to absorb water injected.

Water injection test area borders advance support and its first 20 m outside is regarded as static pressure zone which adopts dynamic pressure water injection. The area between advance support and working face is regarded as dynamic pressure zone which adopts static pressure water injection. With the process of production, the conversion between dynamic pressure water injection and static pressure water injection is easy to regard the dynamic changes of the advance support position as gist, so the preliminary estimation of dynamic pressure water injection is at a distance from static pressure water injection of advance support working face is about 80 m.

When water injects, the water injection pressure is adjusted by the pressure table on the injection pump and the water injection rate showed by corresponding flow meter. Each borehole is equipped with an independent flow meter to facilitate the statistical effect and observation of the real-time situation of water injection (Younus and Yim 2015), in order to adjust the water injection pressure parameters, etc.

The water injection pump connects the automatic addition device of water injection additives, the water injection parameters are showed in Table 1, which can be properly adjusted according to the flow rate changes.

Table 1. Parameters of dynamic and static pressure water injection.

Water injection method	Pressure (MPa)	Advance distance (m)
Static pressure	3	80~10
Dynamic pressure	5~18	80~100

4.2 Examination of high pressure water injection in coal seam

a) Water injection and moisture increment

Using the previous method for practical testing, Figure 8 is the coal water incremental distribution and wetting radius schematic.

Figure 8. Coal water incremental distribution and wetting radius schematic.

Based on the analysis of total water content of coal in different locations in point 163 to point 169 and borehole water injection volume, it can be drawn that the wetting effect of No. 2 and No. 3 borehole is better than others. Specifically, the range between east 6.5 m and west 8 m of No.2 borehole, which is about 90 m from the face, is with a

good wetting effect, water content increased by more than 1%; the range between east 9 m and drilling position of No.2 borehole, which is about 120 m from the face, is with a good wetting effect, water content increased by 1%~2.5%.

Through analysis, coal seam wetting radius of 5304 working face is about 7.8m, so the drilling holes spacing is set to 15 m (Cheng et al 2012, Zhou et al 2015). The average moisture content of coal of No.1 borehole at point 165 is 3.21%, the increase is 1.03%; the average moisture content of coal of No.2 borehole at point 167 is 3.99%, the increase is 1.81%; the average moisture content of coal of No.3 borehole at point 169 is 4.16%, the increase is 1.97%. It can be seen that a good level of application has been achieved.

b) Dust-removal effect

To examine the effect of water injection at working face, dust concentration o before and after water injection is tested, Table 2 shows the main dust concentration records of No.3 borehole.

Table 2. Dust concentration of different process before and after water injection.

Test point	Before injection (mg/m ³)		After injection (mg/m ³)		Dust reduction rate (%)	
	Respirable dust	Full dust	Respirable dust	Full dust	Respirable dust	Full dust
1	156.60	513.25	63.3	187.45	59.58	63.48
2	285.40	835.15	82.5	275.5	71.09	67.01
3	118.30	418.25	49.95	152.4	57.78	63.56
4	175.83	439.17	68.5	190.65	61.04	56.59
5	51.67	261.67	26.65	131.9	48.42	49.59
6	47.50	137.50	22.9	68	51.79	50.55
7	52.50	131.67	23.5	58.75	55.24	55.38
8	28.33	78.33	16.3	44.5	42.47	43.19

According to the dust concentration records, the average moisture content of coal of No.1 borehole at point 165 is 3.21%, the increase is 1.03%, dust-removal rate of c falling coal and moving frame operations achieve 51.32% and 47.02%, the maximum dust-removal rate of multiple processes is 53%; the average moisture content of coal of No.2 borehole at point 167 is 3.99%, the increase is 1.81%, dust-removal rate of coal falling coal and moving frame operations achieve 67.01% and 63.56%; the average moisture content of coal of No.3 borehole at point 169 is 4.16%, the increase is 1.97%, dust-removal rate of coal falling coal and moving frame operations achieve 72.15% and 68.58%. It is estimated that the average increase in water is more than 1.5%, average dust-removal rate of coal falling and shift supports operations achieve 63.49% and 59.72%. The effect of coal seam water injection on dust removal is the best for coal falling process.

5. Conclusions

a) The process of wetting coal by coal seam water injection is analyzed from microcosmic aspect, the influence of water

injection time and water injection pressure on the wetting of coal was analyzed by numerical simulation method, based on this, the water injection parameters suitable for the 5304 working face in Tangkou Mine were determined, and the high-pressure and low-porosity coal seam water injection technology was established.

b) After the application of the water injection process, the average water content of 5304 working face is increased by more than 1.5%, average dust-removal rate of coal falling and shift supports operations achieve 63.49% and 59.72%, the maximum dust-removal rate of multiple processes is 53%, the effect of coal seam water injection on dust removal is the best for coal falling process, a good level of application has been achieved

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References

- Chen, S., L. Jin, D. Ma, and W. Wang, 2011. Experimental study on water absorption of coal under different pressure source conditions. *Procedia Engineering*, 26: 918 - 921.
- Cheng, W.M., W. Nie, G. Zhou, Y. Yu, Y. Ma and J. Xue, 2012. Research and practice on fluctuation water injection technology at low permeability coal seam. *Safety Science*, 50(4): 851 - 856.
- Li, J.K., B.J. Gong, and M.Y. Zhao, 2006. Coal seam water injection research and application. *Coal Technology*, 6: 72.
- Jin, L.Z., Q.G. Fu, B.H. Ren and J. Wu, 2001. Test of dust fall by adding the dust-adhering bar when coal seam water-infused. *Journal of University of Science and Technology Beijing*, 23(1): 1 - 5.
- Jin, L. and S. Ou, 2005. Effect of dust-sticking bar's solution on the contact angle of coal seam in infusion. *Journal of University of Science and Technology Beijing*, 27(3): 264 - 267.
- Ma, Z., Y. Wang and L. Zhang, 2009. Application of long-hole water injecting into coal seam at Chang gou yu colliery. *Journal of Liaoning Technical University (Natural Science)*, 6: 006.
- Nie, B.S., X.Q. He, Z.H. Feng and J.F. Zhang, 2007. Application of magnetized water in coal seam water infusion. *Journal of Liaoning Technical University*, 26(1): 1 - 3.
- Nie, W., C.Q. Su, W.M. Cheng, Y.B. Yu, Z.X. Yang and C.T. Gao, 2011. Design of water injection technique for high ground pressure low cracking rate seam pressure. *Coal Science and Technology. Beijing*, 39: 59 - 62.
- Wang, W.H., 2011. Application present status and outlook of seam water injection dust control technology. *Coal Science and Technology*, 39(1): 57 - 60.
- Wu, J., S. Li and J. Guo, 2012. Dust control technology of coal seam water injection at upper level drilling site. *Journal of Liaoning Technical University (Natural Science)*, 5: 33.
- Wu, G.Y., K. Liu, S. J. Guo, Y. X. Chen and Y. Liu, 2008. Dust reduction by water injection into coal seam of fully mechanized top-coal caving face. *Journal of Mining & Safety Engineering*, 1: 24.
- Younus, I. and M.S. Yim, 2015. Out-containment mitigation of gaseous iodine by alkaline spray in severe accident situation. *Progress in Nuclear Energy*, 83: 167 - 176.
- Zhao, Z.Q., 2000. Study of dust extinguishing by magnetization water. *Industrial Safety and Dust Control*, 7: 44 - 45.
- Zhou, G., Y. Yu, J. Wen, W. Nie and H. Wang, 2015. Numerical simulation of seepage pressure field of coal seam water-injection in high and low pressure with one-way and bi-directional drilling holes. *Industrial Electronics and Engineering*, 93: 155.